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RESEARCH: A RETROSPECT[1]

Inasmuch as the prime object of Sigma Xi is to encourage research by honoring those who possess that rare and priceless gift which we designate as research ability, it seems fitting on this occasion that an attempt be made to illustrate the more important of the varied qualifications essential to success in this high calling.

Among the rare gifts which must be possessed in greater or less degree, intellectual curiosity to know and understand the universe may be singled out as an absolute essential, because perhaps it is the real motive which urges us to investigate. Indeed, may we not say that curiosity is that elusive something which causes organisms to evolve, that upward urge which makes us forever unsatisfied with present attainments. Given that inner urge which intellectual curiosity supplies and even mediocre ability as an observer or some intuition and imagination (attributes which are prime essentials in inductive reasoning) or ability to reason deductively, or all of these, and an investigator is sure to result. Some have all these gifts in a high degree and, if developed, the result is an Aristotle, an Hipparchus, a Roger Bacon, a Darwin, a Faraday or a Newton.

I shall take the liberty of first illustrating these essential qualifications by a brief reference to a history of one of the most fascinating quests which has ever led man to explore the unknown, namely the problem of understanding the universe. In its larger implication we mean by this the problem of finding the position, motion and relationship of each part to every other and the actions and interactions of every conceivable and inconceivable kind between each and every part, including man himself, his inner consciousness and his spiritual nature,—a problem infinite in its scope and in the sweep it allows to the imagination. Only a being divinely endowed, as is man, with the possibility of infinite perfectability would ever contemplate attempting such a task. The most highly gifted race which the world has known attempted to solve this problem by direct assault. Perhaps the most valuable lesson which the ancient Greeks have given to mankind is that the fortifications must be gradually reduced before there is any hope of taking the citadel. I shall, therefore, confine my remarks to a brief outline of the history of the progress which the human race has made in un-

[1] Address to Sigma Xi Initiates at Cornell University, May 15, 1925.

derstanding that small part of this problem which is concerned with finding the positions, motions, actions and interactions of the heavenly bodies. A knowledge of the essential steps in the progress of this phase of the problem of science is a most essential part of the mental equipment of all research workers, because we have here the most complete and easily understood panorama presenting the whole outline of the method of science.

Even before the dawn of written records, man's curiosity about those objects external to his world and hence out of his reach had caused him to complete what is possibly the most notable research in his long history. Reference is made to the discovery that there are two classes of bodies among the heavenly host, namely, the seven wandering bodies, the Sun, the Moon, Mercury, Venus, Mars, Jupiter and Saturn; and the much larger group, the fixed stars. For at least six thousand years, man's curiosity about the so-called fixed stars was in abeyance while he wrestled with the problem which more intensely aroused his curiosity,—the problem of completely explaining the apparently complex motions and relations of the seven wandering bodies. In all this time, the stars were of chief concern only in giving fixed reference points on the sky to be used to mark the stations on the apparent paths of the wandering bodies. In addition, they proved useful in making possible the solution of such problems as the shape and size of his own abode, the Earth, and determining his own position upon it, as well as in marking times and seasons.

Some unknown genius after the time of Thales, but before the time of Aristotle, discovered the rotund form of the earth, an induction based upon the observations of travelers before him and suggested by an idealistic notion that the sphere is the only perfect shape. Eratosthenes, a quarter millennium before Christ, was able to measure the circumference of the earth with a remarkably high degree of precision for that time. Aristarchus, over a century earlier, had determined with considerable accuracy the distance to the Moon in terms of the Earth's diameter. He also used a perfectly valid method for determining the distance to the Sun in terms of the Moon's distance,—a method, however, which is not capable of giving a very high degree of precision. It did, nevertheless, serve a useful purpose in giving a knowledge of the fact that the Sun is much farther away than the Moon and is a larger body than the earth. These early measures were important in giving some information about the relation of man's abode to those heavenly bodies which are most conspicuous and most important to him.

From observations of the stars made by Aristillus and Timocharis, the first astronomers at the Alexandrian University, Hipparchus, about 150 years later, detected the precession of the equinoxes. Hipparchus was also the first to attack systematically the problem of explaining as the resultant of simple motions, the apparently complex motions of the Sun, Moon, and five bright planets. In the absence of the fundamental science of dynamics his explanation was purely kinematical and he made this as simple as possible by following the dictum of Plato in regarding the actual motion as the resultant of a combination of uniform circular motions. The ingenuity and intellectual ability shown by Hipparchus in devising a simple system, consonant with the knowledge of his time, so well suited to explain the observed phenomena and to be used as the basis of deduction for the future, place him among the greatest research men of all time. The detailed working out of his system for the planets awaited more extended observations than could be made in one man's life, and was completed by his admirer, Ptolemy, three centuries later. This system of epicycles and eccentrics devised by Hipparchus, and completed by Ptolemy about 150 A. D. held practically undisputed sway for almost fifteen centuries after the publication of Ptolemy's Almagest. It was only finally displaced by the observations of Tycho Brahe, which in the hands of Kepler led to the discovery of the latter's three laws of planetary motion. These laws of Kepler's were the basis for the great Newtonian induction of a universal gravitative force varying inversely as the square of the distance between the centers of attraction. These laws, with the experimental work of Galileo in dynamics, also led Newton to divine the laws of motion.

The laws of motion and the law of gravitation are the basis of a dynamical system so complete and so satisfactory that even to-day, with the precision of observations far surpassing the wildest hopes of such keen and careful observers as Tycho Brahe, Flamstead, or even Bradley, only one minute discrepancy exists between observation and what Newtonian theory predicts. Even this discrepancy is most probably due to lack of sufficient refinement in our observations or a lack of knowledge of some more elusive force than gravitation, or of both of these.

But my object now is not to minutely review that most brilliant epoch in the history of science, beginning with Tycho Brahe, Galileo and Kepler, culminating in Newton and ending with Laplace, a period which at its end saw the problem of the structure of the solar system completely solved so far as dynamical considerations were concerned. All the steps in the scientific method are illustrated by the achievement of this period and it constitutes the most complete illustration which we possess.

This period and its solution of one phase of the problem of the structure of the universe is but an episode in the gradual revealing of the throbbing life of the universe. Sir William Herschel was the pioneer in recalling man's interest to the larger problem of determining the structure of our galactic system. "He pierced the barrier of the skies" and reawakened man's slumbering curiosity about the stars, a curiosity which was further stimulated by the revelations which the vibrant ether brings us in the form of light. Newton commenced the research which revealed the composite nature of white light and the possibility by its analysis of learning something of its nature. He was only prevented from going further by the imperfection in the art of glass making. Fraunhofer immensely improved said art and his curiosity, stimulated by the discovery of nature's marvelous hieroglyphics, which in deference to his great genius we have named the Fraunhofer lines, made vast strides in their interpretation. Together with this, the further leap made by Kirchhoff opened up vast new vistas, not only into our galactic system, but into the marvellous beauty and order revealed in the vibrant atom, that infinitesimal little galaxy of electrons and perhaps of even still smaller units. The discovery of the principles of spectrum analysis and the new conceptions which it has opened before our vision make clear other relationships than merely dynamical which are undermining the vicious hold and influence which the conception of the universe as a vast machine or an assemblage of intricate mechanisms has had upon the human race. It has been one of the profoundest facts revealing to us the unity of the universe and at the same time enormously extending our conception of it.

That some at least of the nebulae were distant galactic systems was conjectured by Herschel, and later, when the spectroscope made possible a scientific classification of these objects, many keen-visioned souls conjectured yet more confidently that the spiral nebula are distinct galactic systems.

The discovery of novae in the spirals and the ability to recognize them as a distinct class of celestial bodies further confirmed this conjecture and raised it to the rank of a hypothesis. The telescopic and spectroscopic revelations of systems of stars among the vast assemblage of our galactic host, has made possible a more complete solution of the problem of its structure, possibilities greatly increased by the discovery of those marvellous pulsating suns known as cepheid variables. Study of these variables in globular systems of stars, together with spectroscopic evidence as to intrinsic brilliance of stars, made possible to Shapley, a decade ago, the means of determining the distance of these globular clusters whose inner structure may be divined through observations combined with deduction from dynamical principles. By the aid of great telescopes and spectroscopes, made possible by the tremendous advances in engineering and optical skill, Hubble and others have partially resolved the nearer spirals into stars. Among these stars are cepheid variables and just as they have been the plummet which has enabled us to sound the depths of our own galactic system, so now they confirm still more certainly the conception that the spiral nebulae are distant galactic systems. A million of these are now within our ken by using to the full our present means of exploring them.

What wonders and marvels await the seeing eye and the understanding mind no man can tell, but certain it is that when the history of our own epoch is written in some far distant day, it will be justly regarded the most interesting time before 1925 in which to live, the one in which the finest opportunities are open to the intellectually curious who also develop to the full the mental capacity with which they are endowed.

Initiates, your election to this society is in itself evidence that you have this intellectual curiosity and have at least partially developed the mental capacities with which you are endowed. See to it that you let not this torch slip from you—develop your research capacity to the full and carry on the torch of science to light the new world which is to be. So live, in the light of what biological science is revealing, as to have strong and healthy bodies, the abodes of spirits sensitive to receive impulses over the widest possible range of notes from the vibrant, throbbing life of the universe.

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DROSOPHILA AND THE MUTATION HYPOTHESIS

FOR two decades the hypothesis of mutation or the saltatory origin of species has enjoyed a large vogue in American biological laboratories. In its present form, it was first formulated on the botanical side as the result of the investigations of the Dutch physiologist, De Vries, on Lamarck's evening primrose, *Oenothera lamarckiana.* In this species De Vries, as is well known, observed the appearance of a relatively small number of forms from seed, which differed in marked degree from the parent species. This author gave names to these variants and considered them to be elementary or inchoative species. Subsequently it was observed that many of the species of the genus Oenothera were capable of acting in the same manner as *O. lamarckiana,* in cultures and in a few cases the number of aberrant individuals differ-